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The effects of spatial frequency on the accommodation responses of myopes and emmetropes under various detection demands

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ABSTRACT

The dependence of spatial frequency on accommodation has been investigated extensively. Recently, differences between myopes and emmetropes with respect to accommodative microfluctuations for high spatial frequency targets have been reported. Considering the diversity of accommodative responses (ARs) to sinusoidal gratings among subjects, this experiment was designed to analyze the contrast dependence of ARs to targets with various spatial frequencies (SFs). Here, we continuously measured ARs, microfluctuations, and pupil diameter while emmetropic and myopic adult subjects fixated on sinusoidal grating targets of various SFs under standard and near-detection threshold contrast conditions. We first evaluated the detection contrast thresholds at six SFs (2–16 cpd) using a near-contrast sensitivity function test that simulated the CSV-1000 test with a tablet computer. We found no difference in contrast threshold between emmetropes and myopes. We then measured the dynamic ARs to 24 grating targets: six SFs and four contrasts (standard, detection threshold, subthreshold and suprathreshold) were recorded for 30 s. Under standard contrast conditions, we observed a decrease in AR with increasing spatial frequency. Variations in pupil diameter and accommodation were the smallest at 6 cpd. Both the ARs and microfluctuations were higher under near-threshold contrast conditions than under standard contrast conditions, and no variations were found across SFs under near-threshold contrast conditions. No differences in ARs or microfluctuations were found between the two refractive groups at any spatial frequency. These findings provided detailed information on accommodative behavior to spatial frequency targets under normal and high-detection demand conditions.

1. Introduction

In the study of accommodation, the characteristics of the viewing target, such as the shape, size (visual angle), brightness, sharpness, contrast and spatial frequency (SF) distribution, are important and may heavily influence the experimental results. Among these features, spatial frequency has been studied extensively. Pioneering research into the effects of SF on accommodation has shown that the accommodative response (AR) increased with higher SFs (Charman & Tucker, 1977, 1978; Tucker & Charman, 1987; Tucker, Charman, & Ward, 1986). However, more investigators have confirmed that sinusoidal targets with mid-SFs (usually defined as 3–5 cpd) were the most effective stimuli for accommodation, either because they induced the most accurate AR (Mathews & Kruger, 1994; Owens & Wolfe, 1985) or because they produced the smallest variations (Bour, 1981; Ciuffreda & Rumpf, 1985; Day, Gray, Seidel, & Strang, 2009; Owens, 1980). Moreover, a high level of variability in the ARs to grating targets has been reported by several authors (Bour, 1981; Ciuffreda & Hokoda, 1983; Dul, Ciuffreda, & Fisher, 1988; Owens, 1980). Considering the among-subjects variation in the ARs to sinusoidal gratings, Ciuffreda and Hokoda (1983) proposed that reflex, voluntary, and higher-level perceptual aspects of accommodation might interact in a complex manner during accommodation to simple sinusoidal grating. The mental effort associated with the visual task has been shown to significantly affect the steady-state accommodation level (Winn, Gilmartin, Mortimer, & Edwards, 1991). The instructions to the subject and the influence of higher-level control were the two main factors that affected the results of accommodation studies (Ciuffreda & Hokoda, 1983; Owens, 1980; Stark & Atchison, 1994; Tucker et al., 1986). High-level control of the sub-

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ject's accommodation (Ciuffreda, 1991; Ciuffreda & Hokoda, 1983, 1985) could be achieved by placing the subject at his or her contrast detection threshold, which increases the detection demand of the target because the subject must concentrate on the target to maintain its visibility.

Previous studies have shown that the AR to the decrease in target contrast was quite robust (Bour, 1981; Charman & Tucker, 1978; Ciuffreda & Hokoda, 1985; Ciuffreda, Rosenfield, Rosen, Azimi, & Ong, 1990; Heath, 1956). The decrease of the contrast within a certain range did not increase the accommodation inaccuracy (Schmid et al., 2005; Tucker & Charman, 1986; Ward, 1987). However, when the contrast was markedly reduced, i.e., lower than the cut-off or minimum contrast value for a range of SFs, the accommodative accuracy was compromised (Charman & Heron, 1988; Ciuffreda & Rumpf, 1985; Raymond, Lindblad, & Leibowitz, 1984; Ward, 1987), and the instability was increased (Bour, 1981). For gratings with very low contrast, the steady-state AR would either decrease to a tonic level without viewing targets or increase when subjects actively attempted to keep a perceptually fading grating target in focus as voluntary accommodation associated with cognitive effort is known to increase accommodation accuracy (Kruger, 1980).

Accommodation microfluctuations are believed to represent the accommodation controller's accommodative errors in detecting the direction and magnitude of the required response. Myopes are known to exhibit greater accommodative microfluctuations (AMFs) than do emmetropes (Day, Seidel, Gray, & Strang, 2009; Day, Strang, Seidel, Gray, & Mallen, 2006; Langaas et al., 2008; Seidel, Gray, & Heron, 2003). This difference indicates that the ARs of emmetropes might be more stable than those of myopes. In a recent study, this difference in AMFs between myopes and emmetropes was confirmed using 16 cpd SF targets (Day, Gray, et al., 2009). However, the authors compared the increased value of AMFs at 16 cpd with that at 4 cpd but did not compare the real value of AMFs at 16 cpd between these two refractive groups. Therefore, it would be interesting to clarify whether myopes and emmetropes exhibit distinct accommodative behaviors when fixating on grating targets with specific SFs.

Although sine wave targets are unnatural stimuli that are not normally encountered during habitual visual tasks, they are found in almost all visual images. The study of ARs to spatial frequency targets could improve our understanding of the accommodative performance in response to complex targets. Because many visual tasks require prolonged detection and because brief measurement may overestimate the functional resolution of fine details (Raymond & Leibowitz, 1985), the continuous ARs of emmetropes and myopes to a broad range of SFs under normal detection demands (i.e., standard contrast) and under high detection demands (i.e., near-threshold contrast) were evaluated to confirm the high-level control effects on accommodation behavior.

2. Methods

2.1. Participants

A total of 41 adults (24.3 ± 3.4 years old; range, 20–32 years old) participated in the study: 21 emmetropes (spherical equivalent [SE]: 0.2 ± 0.2 D, −0.25 D to +0.50 D, non-cycloplegic subjective refraction) and 20 myopes (SE: −3.1 ± 1.4 D, −1.00 D to −5.50 D). All of the subjects had astigmatism of less than 0.75 D, no ocular or systemic diseases, and 0.0 logMAR visual acuity or better. Informed consent was obtained from each participant, and the study was approved by the Wenzhou Medical University School of Optometry and Ophthalmology ethics committee and the WEIRC Scientific Committee. The study was conducted in accordance with the Declaration of Helsinki.

All of the myopic subjects were fully corrected with 2-week disposable mid-water content (47%) soft contact lenses (Acuvue, Johnson & Johnson, UK), which they inserted at least 15 min before any measurements to ensure adaptation.

2.2. Procedures

2.2.1. Determination of the detection threshold contrast for various SFs

The targets were displayed on a 7″ tablet computer (Nexus 7, Google Inc., 2013 model). The subjects viewed the targets monocularly with the right eye from a chinrest placed 40 cm away from the tablet. The left eye was occluded. Sine wave Gabor targets of 2, 4, 6, 8, 12 and 16 cpd were presented at the center of the screen (angular subtense: 5°; average luminance of the background: 95 cd/m^2). Horizontal and vertical grating targets of those six SFs appeared in descending-contrast random order. The changes in contrast between two steps of each spatial frequency followed the contrast variation of the grating targets of the CSV-1000 (VectorVision, Greenville, OH, USA). In a successive forced-choice procedure, the subjects were asked to choose the direction of the gratings (horizontal or vertical) using a game pad. The contrast values for wrong answers and answers indicating a lack of recognition (pushing the "unable to tell" button) were used to calculate the detection thresholds for each spatial frequency, which were determined using the mean value of three measurements. The contrast sensitivity function was plotted against the reciprocals of the participant's contrast thresholds for various SFs. The contrast value determined by the contrast sensitivity function was used to present threshold targets: one unit lower/higher in contrast than the threshold value corresponded to the subthreshold/suprathreshold target. These 3 values will be referred to as the near-threshold contrast targets.

2.2.2. Measurement of the dynamic AR to six SF targets of various contrasts

During the next step of our experiment, after a 5-min break, the dynamic ARs were measured using a Grand Seiko WAM-5500 open-field autorefractor (Grand Seiko, Hiroshima, Japan) while the subjects viewed Gabor targets of vertical gratings. A total of 24 gratings were displayed for 30 s each; the targets included six SFs and four contrasts (standard contrast matched to the standard contrast value of the corresponding SF on the CSV-1000, threshold contrast, subthreshold contrast and suprathreshold contrast). These targets were presented in a random order with an interval of at least thirty seconds between each measurement. During high-speed mode, the autorefractor was connected to a computer to continuously measure the ARs and pupil diameters for each target, and data were recorded every 0.2 s. During recording, the subjects were instructed to fixate on the center of the target and to keep it as clear as possible.

2.3. Data analysis

Customized software for the Grand Seiko WAM-5500 in high-speed mode was used to automatically remove abnormal data values caused by blinking during recording. Two measurements before and after the abnormal values were also removed. The average values and standard deviations (SDs) of the ARs to SF targets for various contrasts over 30 s were examined. Repeated measures ANOVA and post hoc tests (Fisher's LSD) were performed to assess the differences in the ARs between refractive groups under various SF testing conditions.

3. Results

3.1. Contrast sensitivity function

The contrast sensitivity functions at 40 cm in the myopic and emmetropic groups are illustrated in Fig. 1. These contrast detection thresholds determined the contrast values that were used in the subsequent accommodation measurement (Table 1). In accordance with former reports, contrast sensitivity was significantly higher for mid-range SFs (4 cpd) and decreased rapidly for higher SFs ($F = 248.42$, $P < 0.001$). There was no significant difference in contrast sensitivity between the emmetropic and myopic groups for the tested SFs ($F = 1.406$, $P = 0.237$).

3.2. Accommodative response

For the standard contrast grating targets, the ARs differed among SFs. Overall, the AR decreased with increasing SFs ($F = 11.080$, $P < 0.001$). In particular, the ARs to 16 cpd grating targets were much smaller than the ARs to 2 cpd targets (LSD: $P < 0.01$). Under near-threshold contrast conditions (threshold, subthreshold and suprathreshold), the ARs did not differ among the contrast groups or among SFs. Compared to the standard contrast conditions, the ARs to near-threshold contrast grating targets were greater at higher SFs (8, 12 and 16 cpd; $F = 3.138$, $P = 0.038$; $F = 3.207$, $P = 0.026$; $F = 12.535$, $P < 0.001$, respectively) but not at lower SFs (2, 4 and 6 cpd; Fig. 2).

Fig. 3 shows the ARs to the standard contrast grating targets for myopes and emmetropes. There were no significant differences in ARs between the myopic and emmetropic groups ($F = 1.287$, $P = 0.271$). Furthermore, no significant differences in the ARs to near-threshold contrast targets were found between the myopic and emmetropic groups.

3.3. Accommodative microfluctuations

For the standard contrast grating targets, the AMFs, defined according to the SD of AR (Le, Bao, Chen, He, & Lu, 2010), differed among the SFs ($F = 3.583$, $P = 0.011$). The AMFs were smallest for mid-level (6 cpd) SFs, and they increased for low (2 cpd) and high (16 cpd) SFs.

Under near-threshold contrast conditions, the AMFs did not differ significantly among SFs or among the three contrast groups. As Fig. 4 shows, the AMFs for all three of the near-threshold targets were significantly greater than those for standard contrast targets at a SF of 6 cpd ($F = 3.995$, $P = 0.016$). The AMFs for above-threshold targets were significantly greater than those for standard contrast targets at SFs of 4 cpd and 8 cpd ($F = 11.932$, $P = 0.001$; $F = 5.70$, $P = 0.022$).

The changes in AMFs according to SFs did not differ between emmetropes and myopes ($F = 0.363$, $P = 0.808$), although the AMFs of myopes were slightly greater than those of the emmetropes (Fig. 5).

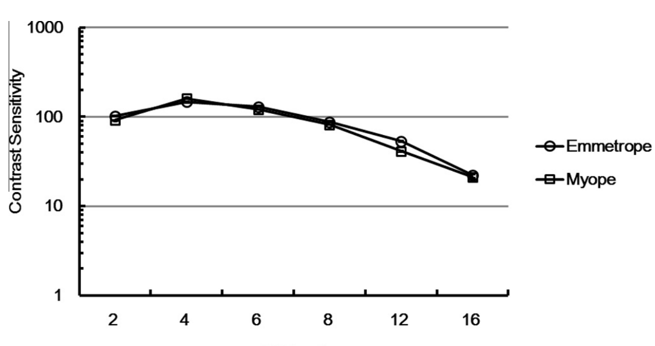

Fig. 1. Contrast sensitivity functions of the emmetropic and myopic groups at 40 cm. Although they are barely noticeable, the error bars represent standard errors.

Table 1
The contrast values (mean ± SD) used to measure the accommodative parameters for each SF.

SF	Standard contrast	Subthreshold contrast	Threshold contrast	Suprathreshold contrast
2	0.63	2.14 ± 0.19	1.99 ± 0.19	1.84 ± 0.19
4	0.76	2.38 ± 0.21	2.23 ± 0.21	2.06 ± 0.18
6	0.91	2.33 ± 0.26	2.19 ± 0.28	2.01 ± 0.25
8	0.78	2.21 ± 0.25	2.07 ± 0.26	1.91 ± 0.24
12	0.61	2.07 ± 0.27	1.92 ± 0.27	1.77 ± 0.27
16	0.30	1.83 ± 0.25	1.69 ± 0.25	1.55 ± 0.25

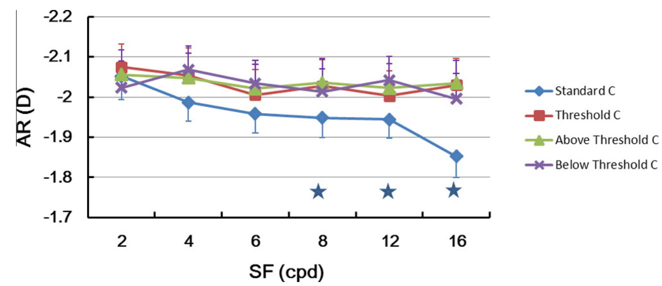

Fig. 2. Accommodative responses (ARs) to grating targets at various spatial frequencies (SFs) under standard and near-threshold contrast (C) conditions. The error bars represent standard errors.

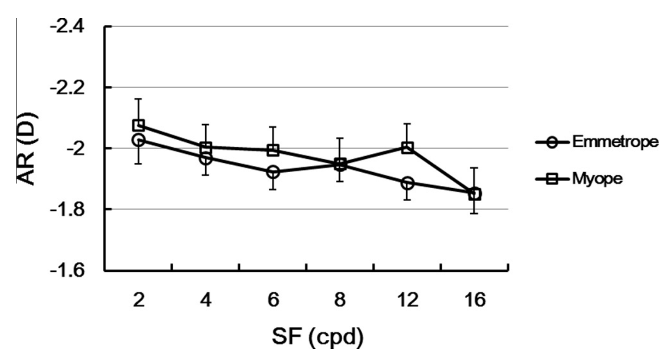

Fig. 3. Accommodative responses (ARs) to standard contrast grating targets at various spatial frequencies (SFs) in emmetropes and myopes at 40 cm. The error bars represent standard errors.

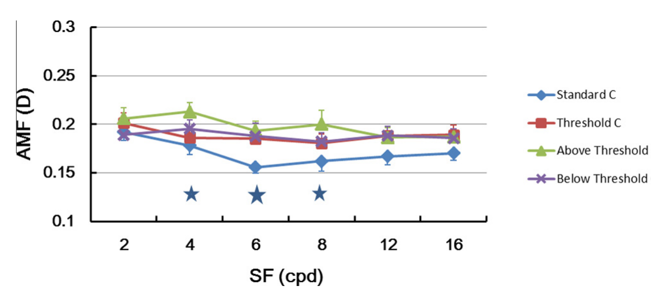

Fig. 4. Accommodative microfluctuations (AMFs) at various spatial frequencies (SFs) under standard and near-threshold contrast (C) conditions. The error bars represent standard errors.

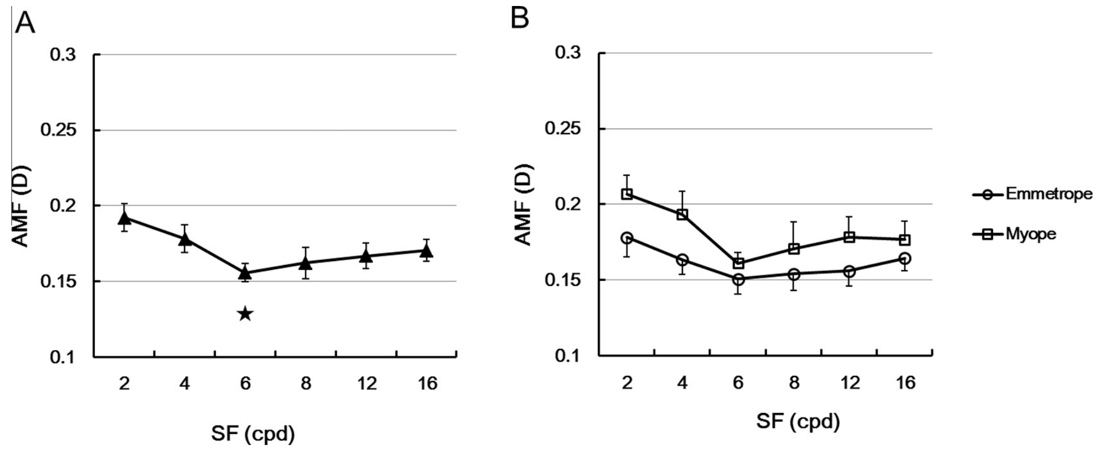

Fig. 5. Accommodative microfluctuations (AMFs) across various spatial frequencies (SFs) under standard contrast conditions (A) for all subjects and (B) for emmetropes and myopes. The error bars represent standard errors.

3.4. Pupil size variation

No significant differences in pupil size were found among SFs or among the contrast target groups. During the continuous recording of AR, pupil diameters fluctuated over a small range within subjects (average standard deviation: 0.28 ± 0.15). Pupil microfluctuations, defined as the SD of the pupil size, showed similar variation patterns to the AMFs across various SFs. The pupil microfluctuations for the standard-contrast targets were smallest for 6 cpd SFs ($F = 2.93$, $P = 0.014$; Fig. 6). However, under near-threshold contrast conditions, there were no significant differences in pupil size variations across SFs (Fig. 7) and no significant difference in the pupil microfluctuations between near-threshold and standard contrast conditions.

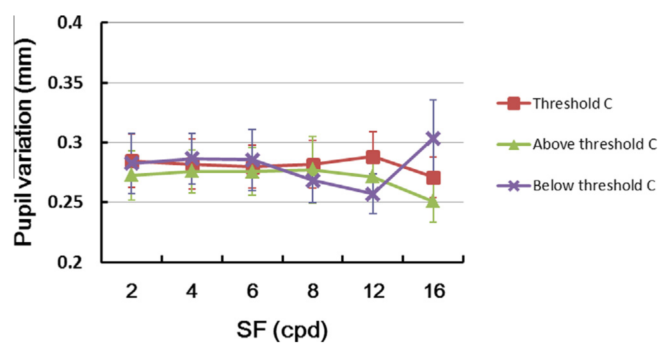

Fig. 7. Pupil variations across various spatial frequencies (SFs) under near-threshold contrast (C) conditions. The error bars represent standard errors.

4. Discussion

4.1. Contrast sensitivity

Contrast detection thresholds were obtained using an automated contrast sensitivity function test that measured how much contrast was required to detect a particular spatial frequency (Kelly, Pang, & Klemencic, 2012). Although the traditional CSV-1000 contrast sensitivity test is usually considered clinically reliable (Pomerance & Evans, 1994), studies have demonstrated that its reliability is low (Kelly et al., 2012). A modified CSF test with an automated descending design presented on a tablet computer was shown to be more efficient and repeatable for obtaining the thresholds we wanted. The procedure worked quickly and consistently, as another study (Yates, Harrison, O'Connor, & Ballentine, 1987) confirmed.

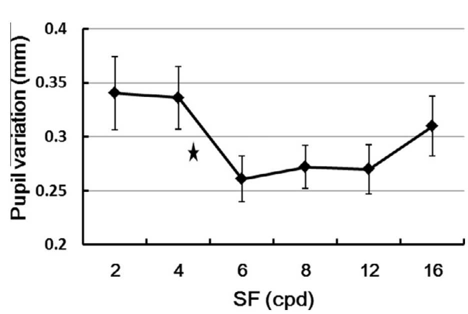

Fig. 6. Pupil variations across various spatial frequencies (SFs) under standard contrast conditions. The error bars represent standard errors.

Our results of the CSF measurements were comparable with findings for a normal range of young people of similar ages (Franco, Silva, Carvalho, Macedo, & Lira, 2010; Pomerance & Evans, 1994; Yates, Harrison, O'Connor, & Ballentine, 1987). No difference in contrast sensitivity function between myopes and emmetropes was found in the present study, in contrast with a previous report (Radhakrishnan, Pardhan, Calver, & O'Leary, 2004) indicating that myopes had reduced contrast sensitivity compared with non-myopes for SFs greater than or equal to 8 cpd. However, our result was in agreement with findings from earlier studies (Bradley, Hook, & Haeseker, 1991; Liou & Chiu, 2001) that used two commercially available printed contrast sensitivity charts (Vistech and Pelli-Robson) and the OPTEC 2000 Contrast Sensitivity System. Even highly myopic subjects were found to have normal contrast sensitivity (Thorn, Corwin, & Comerford, 1986).

4.2. ARs under different contrast conditions

During accommodation measurements, the random presentation of the grating targets (24 gratings with four contrasts) was meant to ensure that the same instructions were given to subjects for different contrast gratings and to avoid contrast adaptation, thus increasing the accuracy and reliability of the results. However, different subjects may still have used different accommodation strategies, even under similar experimental conditions and instructions.

4.2.1. ARs under the standard contrast condition

Owens and Wolfe indicated that the AR was more accurate for 4.2 cpd gratings than for either 1 or 6.5 cpd gratings at all flicker frequencies (Owens & Wolfe, 1985). They suggested that the mechanisms that controlled steady-state accommodation were identical to those used for foveal contrast resolution because 4.2 cpd fell near the peak of the contrast sensitivity function. Later, Ward (1987) reported that the ARs to SF targets of 1.67 and 5 cpd were both good and stable. Furthermore, a recent study showed little variation in the static level of accommodation as the SF of target was altered (Niwa & Tokoro, 1998). In the present study, 2 cpd was set as the lowest spatial frequency because it has been reported that the AR is less accurate for gratings with low SFs ($\leqslant$1 cpd) (Tucker & Charman, 1986). Our data showed that for standard contrast targets, most subjects decreased the accommodation effort when the SF was increased. The AR was highest at 2 cpd and gradually declined with increasing SFs, partially in accordance with the results of Owens (1980). His data showed that ARs were highest at 1.2 and 3 cpd at a proximity of 2.5 D and then decreased with increasing SFs. Our results support the view that high SFs are relatively weak accommodative stimuli.

4.2.2. AR under near-threshold contrast conditions

Some early studies indicated that the observer failed to focus when the contrast of an image was too low to be visible (Bour, 1981; Ciuffreda & Rumpf, 1985; Ward, 1987). An empty visual field would place the accommodation system under open-loop conditions. However, the present results showed significantly higher ARs to near-threshold contrast targets in medium and high SFs, but not relatively low SFs, compared with the ARs to the standard contrast condition. It has been reported that the AR contrast threshold (the contrast level below which the stimulus does not produce an AR) for a 15 cpd grating was much higher than the contrast thresholds for 1.67 and 5 cpd gratings (Ward, 1987). Moreover, contrast had a greater influence on high SFs than on low SFs: low SF gratings could be detected at much lower luminance levels than high SF gratings (Tucker et al., 1986). Therefore, for high SFs, "searching" for an appropriate accommodative stimulus may cause the higher AR because of the greatly faded gratings (Ward, 1987). For low SFs, the retinal image changed little with contrast decline because the characteristics of the optimal transfer function and the ARs were relatively steady (Mathews & Kruger, 1994). As a result, under near-threshold contrast conditions, the ARs to near-threshold contrast targets were similar across SFs. This condition demonstrated a response profile described by the SF independence hypothesis suggested by Ciuffreda and Hokoda (1985): when the subjects used maximum effort, the responses to targets between 0.5 and 16 cpd were equally accurate. The increased ARs to near-threshold contrast targets compared with the ARs under standard contrast conditions also demonstrated that sharp edges were not necessary for accurate ARs (Owens, 1980).

The near-threshold contrast might also have induced a more voluntary AR because in the present study, the subjects were instructed to attempt to keep the target clear during the accommodation recording. In Owen's study (1980), although the subjects were instructed to view the gratings "naturally, without straining the eye," they nevertheless reported that they could improve the apparent contrast of high frequency gratings by exerting effort. A previous study indicated that the amount of contrast required for "accurate accommodation" was approximately 10 times that needed for detection (Raymond et al., 1984). Here, accurate accommodation mainly referred to reflexive, rather than voluntary, accommodation. Furthermore, in our experiment, the round edges of the grating targets might have provided limited peripheral stimulation for accommodation, which could in turn have induced higher ARs; a previous study showed that a stimulus located 2° from the fovea could also influence the accommodation system (Ward, 1987).

4.3. AMFs under different contrast conditions

4.3.1. AMFs under the standard contrast condition

Several studies have investigated microfluctuations in response to SF targets (Bour, 1981; Day, Gray, et al., 2009; Niwa & Tokoro, 1998). Bour (1981) found that under optimal contrast conditions, accommodative fluctuations were larger at 16 cpd than at 4 cpd. Niwa and Tokoro (1998) found that the low frequency components of microfluctuations decreased in the intermediate range of SFs. A study by Day, Gray, et al. (2009) reported that microfluctuations were smallest for SFs of 2 and 4 cpd and indicated that for mid-range SFs, the corresponding cortical image had a steep contrast gradient because the modulation transfer was high. When SFs are above or below mid-range, the contrast gradient is shallower, and greater AMFs may be induced because larger changes in the lens are needed to detect the visual target. Similar to the previous findings, this study revealed that AMFs were smallest at 6 cpd, and they increased for relatively lower and higher SFs under standard contrast conditions. Although previous studies did not measure responses at 6 cpd, this value is within the mid-range of SFs. The variation in AMFs across SFs under standard contrast conditions was also in agreement with the contrast-control hypothesis (Ciuffreda & Hokoda, 1983; Owens, 1980), which assumes that ARs are most stable over the mid-range (4–6 cpd) of SFs, where contrast sensitivity is also maximal. Under standard contrast conditions, even with some voluntary accommodation, the fluctuations of accommodation seem to be negatively correlated with the psychophysical contrast sensitivity function.

4.3.2. AMFs under near-threshold contrast conditions

In this study, AMFs to grating targets were significantly higher under near-threshold contrast conditions (i.e., when the central grating target was nearly invisible) than under standard contrast conditions. Raymond et al. (1984) also indicated that for sustained visual tasks, accommodative stability would be impaired under low-contrast conditions and that the minimum contrast required to stabilize accommodation was higher than that needed for detection. As indicated, the accommodation system used the image information provided by the microfluctuations to determine the required direction of a response (Gray, Winn, & Gilmartin, 1993). When the image quality is degraded by low contrast, the power of the microfluctuations is not sufficient to produce a detectable retinal image (Niwa & Tokoro, 1998); therefore, AMFs increase. In the present study, the increased AMFs were unlikely to be affected by the elevated ARs in the same contrast condition because a change of 0.05 D in the root mean square value of microfluctuations required a 1D change in the steady-state AR (Kotulak & Schor, 1986).

4.4. The pupil and AMFs

Pupil size has a great influence on AMFs (Campbell, Robson, & Westheimer, 1959; Charman & Heron, 1988; Stark & Atchison, 1997). In particular, a small pupil size causes an increase in the magnitude of AMFs (Day, Seidel, et al., 2009; Gray et al., 1993; Stark & Atchison, 1997), mainly in the power of the low frequency components (Gray et al., 1993; Stark & Atchison, 1997); however, for pupil diameters over 2 mm, the fluctuations were relatively constant (Day, Seidel, et al., 2009; Gray et al., 1993). The pupil diameters in this experiment were generally within 4–6 mm, a range over which the depth of focus varies only weakly with pupil diameter (Atchison, Scott, & Smith, 2000); therefore, the accommodative variability based on the pupil size could be ignored.

The present result also shows that variations in pupil size and variations in AR across various SFs have similar patterns. Both pupil fluctuations and AMFs were SF-dependent (Fig. 6). Although some studies have reported that the power of the low-frequency components of AMFs increased with decreasing pupil diameter (Campbell et al., 1959; Gray et al., 1993), to the extent of our knowledge, our study is the first to report the correlation between variations in accommodation and pupil size. The innervation of parasympathetic fibers from the oculomotor nerve, which affects both pupil size and the ciliary muscles that control the AR, could explain these correlations.

4.5. Myopes vs. emmetropes

Elevated AMFs in myopes are believed to constitute a risk factor for the development of myopia (Harb, Thorn, & Troilo, 2006; Langaas et al., 2008). Fluctuations that occur during long-term reading might produce a blur signal that leads to myopia. In a recent study, Day et al. found that compared with emmetropes, adult myopes showed a significantly greater increase in microfluctuations for 16 cpd targets (Day, Gray, et al., 2009). In our study, although the myopes showed slightly higher microfluctuations than did the emmetropes for all SFs, no significant differences between emmetropes and myopes were found at any SF. This finding may be related to the relatively more stable accommodative system in myopic adults. Children with early-onset myopia have been shown to have greater accommodative variability than do emmetropic children (Langaas et al., 2008) when viewing 4D targets on letter charts. A later follow-up study (Langaas & Riddell, 2012) found that children with more rapidly progressive myopia had greater accommodative instability for the 4D target during their initial visits. It remains necessary to verify whether children with early-onset myopia also have greater AMFs when viewing various sine wave targets. The greater AMFs under near -detection threshold conditions observed in this study indicated that extremely low-contrast targets could increase the risk of progression during myopia because greater variability in accommodation could result in increased hyperopic retinal blur.

5. Conclusions

This study investigated the accommodative behavior of myopic and emmetropic adults in response to sine wave targets at various SFs under standard and near-threshold contrast conditions. Various contrast conditions significantly influenced accommodation. ARs and microfluctuations under near-threshold contrast conditions were not SF-dependent, and they were significantly greater than those that occurred under standard contrast conditions. For the standard contrast, the ARs gradually decreased with increasing SFs, whereas the AMFs and pupil variations were smallest for intermediate SFs (6 cpd). No differences in AR or microfluctuations between emmetropic and myopic adults were found in this study.

Commercial relationships

None.

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